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Adequacy of Disinfection for Control of Newly Recognized Waterborne Pathogens

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16. ABSTRACT

Agents recently recognized as causes or potential causes of waterborne outbreaks include pathogenic bacteria (Campylobacter jejuni, Yersinia enterocoliticia), viruses (rotavirus, Norwalk virus and other poorly defined viral agents) and Giardia lamblia, a protozoan agent. Although not a cause of waterborne disease in the classical sense, concern also has been expressed about the relationship of water supplies to the occurrence of legionellosis caused by Legionella pneumophila. New disinfection information on hepatitis A virus (HAV), long established as a cause of waterborne disease, has recently been developed and is included in this report. With the possible exception of Giardia lamblia, waterborne outbreaks caused by these agents seem to occur mainly as a result of deficiencies in treatment, massive contamination of water sources that received inadequate treatment, or contamination after treatment. There is little to indicate that such outbreaks occur in well-operated systems with adequate or conventional treatment.

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ADEQUACY OF DISINFECTION FOR CONTROL OF NEWLY RECOGNIZED WATERBORNE PATHOGENS

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INTRODUCTION

The introduction of disinfection as a step in the drinking water treatment process around the turn of the century, along with coagulation and filtration, caused a dramatic decrease in outbreaks of waterborne disease. In the United States disinfection was perhaps the single most important factor in controlling typhoid fever, a waterborne disease that was rampant throughout the world in the 19th century. Cholera and dysentery, also rampant waterborne diseases in the 1800's also declined dramatically with the advent of disinfection. Although the number of cases of waterborne disease outbreaks has been dramatically reduced, outbreaks still occur. Despite improved and intensified outbreak investigations, the etiologic agents responsible for over half of these current outbreaks remain unidentified.

Agents recently recognized as causes or potential causes of waterborne outbreaks include pathogenic bacteria (Campylobacter jejuni, Yersinia enterocolitica), viruses (rotavirus, Norwalk virus and other poorly defined viral agents) and Giardia lamblia, a protozoan agent. Although not a cause of waterborne disease in the classical sense, concern also has been expressed about the relationship of water supplies to the occurrence of legionellosis caused by Legionella pneumophila. New disinfection information on hepatitis A virus (HAV), long established as a cause of waterborne disease, has recently been developed and is included in this report. The current state of knowledge and future plans for developing additional disinfection information relative to these agents will be discussed.

BACTERIAL AGENTS

Campylobacter jejuni

This microorganism has only recently been recognized as an important bacterial enteric pathogen of man (1-4). Domestic and wild animals probably constitute the major reservoir for the organism. It is an intestinal commensal organism in birds and in mammals including cattle, sheep, rodents, swine, dogs and cats (5). A number of waterborne outbreaks have occurred. An outbreak in Bennington, Vermont

in 1978 involving U.S. Environmental Protection Agency 3,000 people was caused by consumption of water from the municipal supply. The supply was unfiltered and inadequately chlorinated (6). An outbreak of Campylobacter enteritis in British Columbia affecting 800 people was attributed to an unchlorinated water supply (7). Another outbreak in Sweden involving 800 people was caused by polluted surface water contamination of a sand filtered, unchlorinated ground water supply (8). In addition to these large outbreaks, Blaser (9) in a study of Campylobacter enteritis in Denver, suggested that campers and backpackers, drinking untreated water from streams, accounted for up to 5 percent of the cases occurring there. Numerous individual cases have been associated with drinking untreated stream water. It should be pointed out that all of the above outbreaks appear to be related to either untreated or inadequately treated drinking water.

Virtually no laboratory studies have been conducted on the resistance of Campylobacter to drinking water disinfectants. Results of a preliminary study reported at the 1982 American Society for Microbiology meeting (10) indicated that Campylobacter was similar to E. coli in its resistance to chlorine. More extensive studies are currently in progress but data are not yet available.

Yersinia enterocolitica

This microorganism is well established as a human pathogen responsible for a variety of gastrointestinal conditions, including acute gastritis, enteritis, terminal ileitis and colitis. It has been isolated from a variety of wild and domestic animals including primarily rodent species (11), dogs (12), deer (13) and frogs (14). In addition there is some indication that the organism may survive and multiply in the free living state in aquatic environments. Y. enterocolitica is capable of growth at low temperatures. This characteristic has been employed in isolation of the organisms from environmental samples by incubating isolation media at refrigerator temperatures. One report also indicates that the organism can multiply under very low nutrient conditions (distilled water)(15).

A number of surveys have demonstrated the presence of Y. enterocolitica in surface waters in Michigan, New York, Colorado, California and Washington, as well as locations in Norway, Belgium, and Canada (16). The organism has been implicated in one waterborne outbreak at a ski resort in which sewage contamination of a chlorinated spring occurred (17). Wetzler (18) also cited a series of case studies relating individual water supplies to occurrence of gastroenteritis in family members consuming the water. The results of the water sample survey portion of Wetzler's study (18) are shown in Table 1. Y. enterocolitica was found in 6 to 8 percent of finished water samples derived from surface waters that had been either chlorinated only or had received other treatment in addition to chlorination. Positive samples were associated with over 40 percent of the 33 utilities included in the survey that used these treatment processes.

Wetzler (18) also presented 11 case histories involving yersiniosis in families using individual water supplies in which the water supply could be implicated as a cause of the disease.

Little information is available from laboratory studies on inactivation of Y. enterocolitica by disinfectants. The results of a very limited study by Scarpino (19) are shown in Fig. 1. The results indicate that Y. enterocolitica is more sensitive to free residual chlorine than E. coli. Currently, additional research is in progress. There is evidence that microorganisms capable of growth under aquatic conditions are more resistant to inactivation by disinfectants when grown under such conditions than the same species grown under high nutrient conditions. Investigation of this aspect is incorporated into the research in progress.

Legionella pneumophila

This pathogen is spread primarily by the respiratory route through aerosols rather than by ingestion as is typical of classical waterborne pathogens. However, because it does occur and multiply under certain conditions in warm water distribution or plumbing systems (primarily hospital hot water systems and cooling towers) it has been of concern to the water supply industry and regulatory agencies. Although not proven at this time, it is generally assumed that the "seed" organisms probably were present in the potable water supplying these plumbing systems.

Laboratory studies have been conducted on the inactivation of L. pneumophila by chlorine and other biocides used in cooling towers (20) and ultraviolet radiation (21). The results from studies using chlorine (20) indicated reduction of viability by at least 6 orders of magnitude almost immediately after response to free residual chlorine at a concentration of 3.3 mg/L. The results of the U.V. radiation studies (21) indicated that L. pneumophila was more sensitive than E. coli and other enteric bacteria. However, the results of subsequent field studies (22, 23) indicated that levels of chlorine and other biocides shown to be effective in laboratory studies were not effective in eliminating L. pneumophila from operating cooling towers.

In a more recent study, Yee and Wadowsky (24) have showed conclusively that L. pneumophila is capable of growth in tap water. Their results showed that numbers increased by more than three orders of magnitude after incubation for 21 days at 37C. Thus, it appears that L. pneumophila may be similar to Y. enterocolitica with regard to ability to grow in aquatic environments although apparently requiring much higher temperatures. Again, the possibility arises that cells grown under such conditions may be more resistant to disinfectants. The field studies (22, 23) offer some support for this. This aspect has been incorporated into currently ongoing L. pneumophila disinfection research although no data are yet available.

VIRAL AGENTS

Nearly all of the literature relating to waterborne transmission of viral diseases and the effects of treatment processes on viral agents deals with enteroviruses (polioviruses, Coxsackie viruses, ECHO viruses). These viruses have only rarely been implicated in waterborne disease outbreaks (25) and have been used primarly as models because of the availability of relatively simple methods for their production and enumeration.

Three different viruses or virus groups appear to be responsible for substantial numbers of waterborne outbreaks: hepatitis A virus (HAV), rotavirus, and Norwalk-like viruses. Of these, only HAV has had a long history of association with waterborne outbreaks. The other two groups have only recently been implicated in such outbreaks. Because of the lack of methods for handling these viruses in the laboratory, little information on inactivation and removal of these agents by water treatment processes is available.

Hepatitis A Virus

As indicated above, this virus has been long established as a cause of waterborne disease transmitted by drinking water. Mosley (25) reviewed some 50 outbreaks worldwide that occurred between 1895 and 1964. A number of additional outbreaks have occurred since 1964. Although Neefe et al (26) reported in 1945 that large amounts of chlorine destroyed infectivity of HAV in crude fecal filtrates, the data provided no information on the comparative resistance of this virus and because of methods problems little additional information has been forthcoming. Recently, Peterson et al (27) conducted more quantitive studies using clean HAV preparations and marmosets for determing HAV viability after exposure to chlorine. A summary of the results of these experiments is shown in Table 2. Reduction of infectivity to zero indicates reduction of infectivity by more than 3 orders of magnitude. The results indicate that this degree of reduction was not always attained after exposure of HAV to 0.5 to 1.5 mg/L of free residual chlorine for 30 minutes at pH 7.0 and 5.0 C.

Although the data cannot be compared directly with more extensive studies of other enteroviruses that replicate in cell cultures, the results suggest that HAV may be somewhat more resistant to chlorine than the model viruses. Additional information is needed. While HAV strains have recently been adapted to cell culture, the quantification methods, employing radioimmuno-assay or other techniques other than plaque assay, lack the sensitivity needed for disinfection studies.

Rotavirus

The literature on this agent was recently reviewed by Blacklow and Cukor (28). Besides human rotavirus, immunologically related rotaviruses that infect calves, pigs, sheep and monkeys are known. Morphologically, rotaviruses are about 70 nm in diameter, have the appearance of spoked wheels and contain double stranded segmented RNA. Gastroenteritis caused by human rotavirus is usually sporadic and occasionally epidemic, occurring predominantly in infants and young children. Typically, it produces severe diarrhea lasting from 5 to 8 days, usually accompanied by fever and vomiting. The virus is transmitted by the fecal-oral route. Recorded waterborne outbreaks have been rare. Water supplies have been implicated in outbreaks in Sweden (29), USSR (30), Brazil (31), and most recently, the U.S. (32). In one instance, the water supply was a manually chlorinated, poorly protected shallow well known to contain high coliform counts (31). One water supply system was described only as contaminated with sewage effluent (29) and in the USSR study (30), the water supply system was not described. The U.S. outbreak, (32) which occurred in Colorado, involved 1130 persons and was linked to

use of a surface supply contaminated with sewage sludge discharged from an overloaded upstream sewage treatment plant. The water received no pretreatment prior to filtration, the filter beds were severely channeled and a chlorinator failure preceded onset of cases of illness. Few laboratory scale disinfection studies on rotavirus have been conducted. Cell culture methods are available for growth of a number of rotaviruses affecting lower animals as well as for human rotavirus. Because better methods are available for the simian rotavirus, the disinfection data available have been developed using this virus. The results of these studies, shown in Table 3, indicate that the simian rotavirus is relatively sensitive to free residual chlorine with 99% inactivation occurring after less than 15 seconds exposure at pH 6.0 and 5°C (33). At pH 10.0, 1.4 minutes were required for 99% inactivation under the same conditions. These results are similar to those for the most sensitive of six enteroviruses previously studied by Engelbrecht et al (34). The results shown in Table 3 indicate that poliovirus 1 is on the order of 10 fold more resistant than the simian rotavirus. These studies are continuing with investigation of human rotavirus inactivation planned for the near future.

Norwalk-like Viruses

A number of antigenically and morphologically similar viral agents are included in this group. They are about 27 nm in diameter, of unknown nucleic acid type, and include at least 3 serotypes (28). They are usually named according to the outbreak location eg., Norwalk, Hawaii, Montgomery County, Marin County, etc. None of these agents have been grown in cell culture.

These waterborne outbreaks differ from those produced by rotavirus in that Norwalk-like outbreaks are characterized by broader scale epidemics involving entire communities and including adults as well as children. The illness is explosive and self-limited, usually lasting only 24 to 48 hours. Signs and symptoms include various combinations and degrees of vomiting, diarrhea, nausea, abdominal cramps, headache, low-grade fever, anorexia, malaise, and myalgia.

The Norwalk-like viruses have been frequently involved in waterborne outbreaks with eight or more incidents reported in the period 1978-80 in the United States (35). Most of these outbreaks have occurred in noncommunity systems serving resorts or camps and usually involving overt contamination of a ground water supply or a surface supply receiving minimal treatment. The only outbreak in the U.S. associated with a large municipal water system occurred in 1980 (36). In this outbreak, affecting about 1,500 persons, an association between gastrointestinal illness and consumption of drinking water was shown. The epidemiological evidence indicated that the outbreak was caused by local contamination in the distribution network of the municipal system through an interconnection with an industrial system. The industrial system was supplied by five wells and two springs, one of which was found to be contaminated. The industrial supply was chlorinated but the chlorination apparatus was antiquated and considered unreliable.

Because of the absence of methods for propagating these viruses in cell culture, conventional laboratory disinfection studies have not been conducted on these viruses. Thus, the only information avail-

able comes from the nature of the systems in which outbreaks have occurred. As indicated above, in all cases the systems appear to have had deficiencies in operation or critical equipment failure.

OTHER AGENTS

Giardia lamblia

Interest in this intestinal parasitic protozoan as a cause of waterborne disease has increased considerably over the past 10-15 years. The primary mode of transmission of giardiasis is by the fecal-oral route. The organism has a life cycle, one stage of which consists of a cyst form in which the organism exists outside the human body. Infection is acquired by ingestion of the cysts which are relatively resistant to physical and chemical factors in the environment, remaining viable for upwards of two months in cold water (37). The available data suggest that some Giardia are not highly host specific and that lower animals (beaver, muskrats, dogs, etc.) serve as reservoirs of this organism in nature (37). This disease may present with a variety of signs and symptoms including epigastric pain, diarrhea, abdominal cramps, malaise, and weight loss. In waterborne outbreaks, a wide range of age and economic groups are usually involved. Giardia has been, and continues to be, the most frequently identified agent involved in waterborne outbreaks in the U.S. At least 18 waterborne giardiasis outbreaks have occurred over the period 1978-80 (35). Twelve of these occurred in community systems. Frequently, these outbreaks occur in small water supply systems that use high-quality, low turbidity surface water sources and often rely on chlorination as the only treatment process

Because of the difficulty in obtaining G. lamblia cysts, relatively little information on the resistance of this organism to chlorine and other disinfectants is available. The results of studies conducted by Jarroll et al (38) are shown in Fig. 2 and 3. The results of studies conducted at 5°C (Fig. 2) indicate that G. lamblia is substantially more resistant to chlorine than enteric bacteria or enteroviruses. At a chlorine concentration of 1 mg/L, upwards of 60 minutes or more were required for 99% inactivation of the cysts. This is in contrast to the virus data in Table 3 indicating 99% reduction in enterovirus viability under similar conditions in less than 4 minutes at half the chlorine concentration. Increasing chlorine concentrations at the same temperature (Fig. 2) and increasing water temperatures (Fig. 3) resulted in corresponding increases in inactivation rates.

Similar results were found in more recent studies by Rice et al. (39). Their results also showed that G. muris cysts were as resistant or more resistant than G. lamblia cysts. G. muris cysts are easily obtained through maintenance of a G. muris infected mouse colony and provide a model for human parasitic protozoan studies. A number of disinfection studies are currently in progress using the G. muris cyst model but no additional studies have been published.

CONCLUSIONS

Newly recognized waterborne pathogens or potentially waterborne pathogens include pathogenic bacteria, viruses, and a protozoan species. With the possible exception of Giardia lamblia, waterborne outbreaks caused by these agents seem to occur mainly as a result

of deficiencies in treatment, massive contamination of water sources that received inadequate treatment, or contamination after treatment. There is little to indicate that such outbreaks occur in well-operated systems with adequate or conventional treatment. For most of the agents, little disinfection information has been developed for a variety of reasons including lack of methods for laboratory manipulation of the agents, lack of a readily available supply of the agent, or because the agent has only recently been recognized as a cause of waterborne disease outbreaks. While none of these agents, with the exception of G. lamblia, appear to have an inordinately high level of resistance to inactivation by disinfectants, the prudent course is to conduct the research needed to determine this rather than relying on supposition, conjecture, and information derived through indirect means.

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TABLE 1. Summary of Yersinia Enterocolitica Recoveries from Washington Waters[a]

Supply Types and Treatment	Number of Utilities	Untreated Water Samples			Treated Water Samples		
		Total	Number Positive	Percent Utilities Positive	Total	Number Positive	Percent Utilities Positive
Surface Cl_2 only	17	171	36 (21.2)[a]	64.7	284	18 (6.3)[a]	41.2
Surface Cl_2 & Other	16	203	36 (17.7)	81.3	181	14 (7.7)	43.8
Ground Cl_2 only	19	146	14 (9.6)	31.6	223	8 (3.6)	31.6
Ground no treatment	5	66	1 (1.5)	20.0	None	None (0)	None
TOTALS	57	586	87 (14.6)	52.6	688	40 (5.8)	40.4

[a]after Wetzler (18)

TABLE 2. Infectivity of Chlorine Treated Partially Purified Hepatitis A Virus in Marmoset Monkeys (Saguinus sp.)[a]

Treatment		No. Hepat.	$\bar{x}$ Inc.	No. Seroconv.	$\bar{x}$ Seroconv
mg HOCl/L	min.	No. Inoc.	Period[b]	No. Inoc.	Day[c]
none	30	3/3	37	3/3	28
	30	2/2	45	2/2	48
		5/5 (100)[d]	40	5/5 (100)[d]	36
0.5	15	1/5	71	2/5	85
	30	1/5	71	2/5	85
	60	0/4	--	0/4	--
		2/14 (14)	71	4/14 (29)	85
1.0	30	0/4	--	2/4	107
	30	1/4	--	1/4	48
	30	0/4	--	1/4	75
		1/12 (8)	--	4/12 (33)	77
1.5	30	1/5	70	1/5	70
	30	0/5	--	0/5	--
		1/10 (10)	70	1/10 (10)	70
2.0	30	0/4	--	0/4	--
	30	0/4	--	0/4	--
		0/8 (0)	--	0/8 (0)	--
2.5	30	0/5 (0)	--	0/5 (0)	--

[a]HAV virus was diluted 1:50 with treatment buffer, pH 7.0, containing the desired level of HOCl at 5°C and treated for indicated time with gentle agitation.
[b]mean incubation in days.
[c]mean seroconversion in days.
[d]percentage which developed hepatitis or seroconverted

From Peterson et al. (27)

TABLE 3. Comparison of Virus Inactivaton by 0.5 mg/L Free Residual Chlorine at pH 6.0 and 10.0, and 5.0°C ± 0.2°C

Virus strain	Minutes for 99% Inactivation		Reference
	pH 6.0	pH 10.0	
Coxsackie A9 (Griggs)	0.3	1.5	34
Echo 1 (Farouk)	0.5	96.0	34
Polio 2 (Lansing)	1.2	64.0	34
Echo 5 (Noyce)	1.3	27.0	34
Polio 1 (Mahoney)	2.1	21.0	34
Coxsackie B5 (Faulkner)	3.4	66.0	34
Rotavirus (Simian, SA-11)	< 0.25	1.4	33

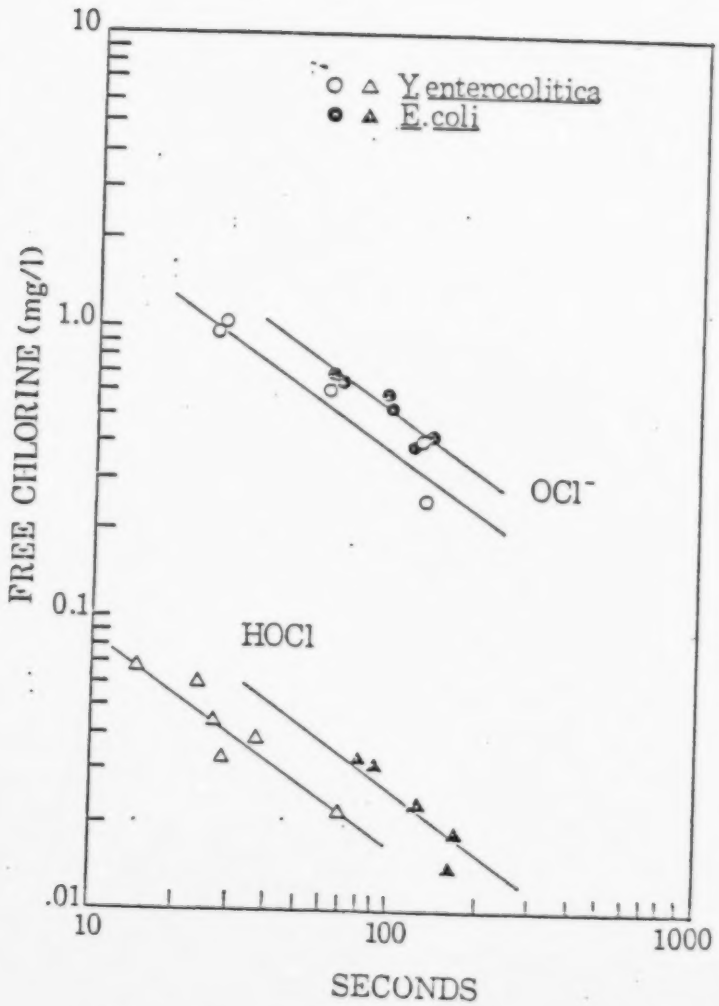

Figure 1. Comparative inactivation rates of E. coli and Y. enterocolitica by HOCl and OCl^- at 5C. After Scarpino (19).

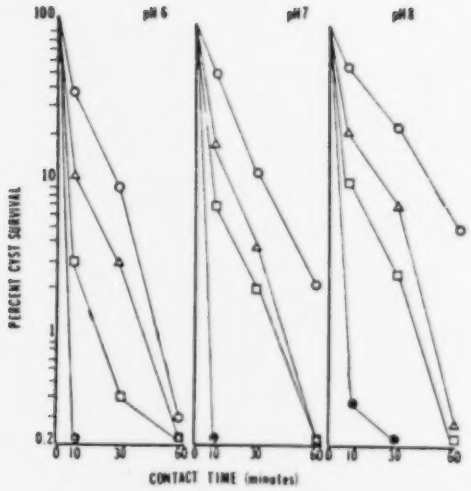

Fig. 2. Inactivation of G. lamblia cysts by free residual chlorine at 5°C: chlorine concentrations are 1 mg/L (○), 2. mg/L (△), 4 mg/L (□) and 8 mg/L (●). From Jarroll et al. (38)

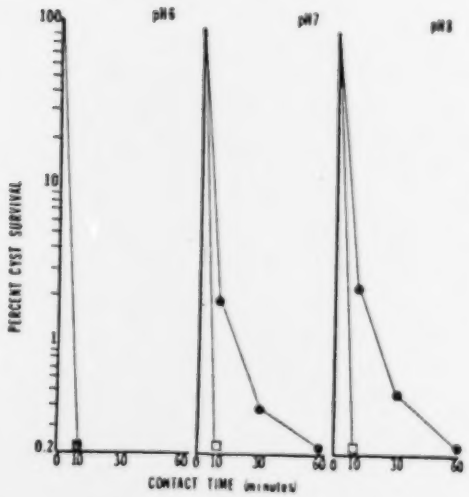

Fig. 3. Inactivation of G. lamblia cysts by free residual chlorine at 15°C. Chlorine concentrations are 2.5 mg/L (●) and 3.0 mg/L (□). From Jarroll et al. (38)